MARKED-UP SPECIFICATION

TITLE: MULTI-STACK OPTICAL DATA STORAGE MEDIUM AND USE OF SUCH MEDIUM

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MULTI-STACK OPTICAL DATA STORAGE MEDIUM AND USE OF SUCH MEDIUM

BACKGROUND OF THE INVENTION

Field Of The Invention

[0001]   The invention relates to a multi-stack optical data storage medium for recording using a focused radiation beam having a wavelength λ and entering through an entrance face of the medium during recording, comprising:

- a first substrate ~~with present~~ having, on a side thereof:

- a first L_0 guide groove formed therein, and

- a first recording stack ~~named~~ L_0, comprising a recordable type L_0 recording layer~~, and formed in a first L_0 guide groove~~, the L_0 recording layer having a thickness d_{L0G} in the groove and a thickness d_{L0L} adjacent the groove, and a first reflective layer present between the L_0 recording layer and the first substrate~~,~~;

- a second substrate ~~with present~~ having, on a side thereof:

- a second L_1 guide groove formed therein, and

- a second recording stack ~~named~~ L_1 comprising a recordable type L_1 recording layer, the L_1 recording layer having a thickness d_{L1G} in the groove and a thickness d_{L1L} ~~adjecent~~ adjacent the groove, said second recording stack being present at a position closer to the entrance face than the L_0 recording stack ~~and formed in a second L_1 guide groove,~~; and

- a transparent spacer layer sandwiched between the recording stacks, said transparent spacer layer having a thickness

substantially larger than the depth of focus of the focused radiation beam.

[0002]   The invention also relates to the use of such a medium.

Description Of The Related Art

[0003]   An embodiment of an optical recording medium as described in the opening paragraph is known from European Patent Application EP1067535A2, corresponding to U.S. Patent Application Publication No. 2005/0063295. The most common embodiment of the medium is a circular disk.

[0004]   Regarding the market for optical recording, it is clear that the most important and successful format so far is a write-once format, Compact Disk Recordable (CD-R). Although the take-over in importance by Compact Disk ReWritable (CD-RW) has been predicted since a long time, the actual market size of CD-R media is still at least an order of magnitude larger than for CD-RW. Furthermore, the most important parameter for drives is the maximum write speed for R-media, not for RW. Of course, a possible shift of the market to CD-RW is still possible, e.g., because of Mount Rainier standardization for CD-RW. However, the R-format has been proven very attractive due to its 100% compatibility with read read-only compact disk (CD).

[0005]   Recently, the Digital Versatile Disk (DVD) has gained marketshare as a medium with a much higher data storage capacity than the CD. Presently, this format is available in a read only

(ROM) and a rewritable (RW) version. Next to the DVD ReWritable (DVD+RW) standard, a new recordable (R), i.e., write once, DVD+R standard was developed. The new DVD+R standard gets increasing attention as an important support for DVD+RW. A possible scenario

5   is that the end customers have become so familiar with an optical write-once format that they might accept it more easily than a re-writable format.

[0006]   An issue for both the R and RW formats is the limited capacity, and therefore recording time, because only single-stacked

10   media are present. Note that for DVD-Video, which is a ROM disk, ~~dual~~ dual-layer media already have a considerable market share. A dual-layer, i.e., dual-stack, DVD+RW disk is probably feasible. However, it has become clear that a fully compatible disk, i.e., within the reflection and modulation specification of the dual-

15   layer DVD-ROM, is very difficult to achieve and requires at least a major breakthrough for the properties of the amorphous/crystalline phase-change materials, which are used as recording layers in, e.g., DVD+RW media. Without a full compatibility, the success of a dual-layer DVD+RW in the market is questionable.

20 [0007]   In order to obtain a dual-layer DVD+R medium which is compatible with the dual-layer DVD-ROM standard, the effective reflectivity of both the upper L_1 layer and the lower L_0 layer should be at least 18%. ~~Effective~~ The term "effective" means that the reflection is measured as the portion of effective light coming

25   back from the medium when both stacks L_0 and L_1 are present and

focusing on L_0 and L_1, respectively. This implies that the L_0 stack as such requires a far higher reflection level of, e.g., more than 50%, preferably more than 60%, because the L_1 stack absorbs a substantial portion of the incoming and outgoing light. It should be noted that in this document, the normally used convention of notation of L_0 and L_1, in which notation L_0 is the "closest" stack, i.e., closest to the radiation beam entrance face, has been changed: L_0 now is the deepest stack and $L_1...L_n$ are stacks closer to the radiation beam entrance face. In EP1067535A2, the following definitions are used: dG1 (corresponding to d_{L1G} in this document) is the thickness of the dye layer in a groove of the first or top information recording/reproduction unit which corresponds to L_1, dG2 (corresponding to d_{L0G} in this document) is the thickness of the dye layer in a groove of the second information recording/reproduction unit which corresponds to L_0. dL1 (corresponding to d_{L1L} in this document) is the thickness of the dye layer on a land corresponding to L_1, dL2 (corresponding to d_{L0L} in this document) is the thickness of the dye layer on a land corresponding to L_0. The depth of the grooves corresponding to L_1 is d1 but the depth of the grooves d2 corresponding to L_0 is defined differently. d2 is the height difference of lands and grooves measured on the dye surface after a dye layer has been coated. dG2, d2 and dL2 are set to approximately 174, 140 and 120 nm. A calculation shows that this corresponds to a groove depth g in the substrate corresponding to L_0 of about 194 nm. Measurements

by applicants have shown that the inverted L_0 stack of the known medium with grooves with a depth of 194 nm has a reflectivity ~~being~~ of only 15% - 50% of the reflectivity of blank areas (i.e., without grooves). This means that it is impossible to reach the desired 60%

5   reflection level because in order to obtain a dual-layer DVD+R medium which is compatible with the dual-layer DVD-ROM standard, the reflectivity of a light beam focused onto the data track of the lower L_0 layer should be sufficiently high (typically > 60%, depending on the transmission of the upper L_1 layer). From a dual-

10 stack DVD+R production point of view, an inverted L_0 layer structure is preferred which means that the recording layer of the L_0 stack is present at a side of the reflective layer other than the side of the substrate with groove structure. In EP1067535A2, it is proposed to that dG1 is substantially equal to dG2 and that dL1

15 is substantially equal to dL2. Furthermore dG1 should be larger than dL1, whereas dG2 should be larger than dL2.

SUMMARY OF THE INVENTION

[0008]   It is an object of the invention to provide an optical

20 data storage medium of the type mentioned in the opening paragraph which has a reflection level of the L_0 stack and a modulation level of recorded marks in the recording layer of the L_0 recording stack which is compatible with the dual-layer DVD-ROM specification.

[0009]   This object ~~has been~~is achieved in accordance with the

25 invention by an optical storage medium, ~~which is~~characterized in

that the depth of the first L_0 guide groove is smaller than 0.15λ and that d_{L0L} is substantially equal to or larger than d_{L1G}. Shallow grooves are proposed in order to achieve a high reflection value of the L_0 stack. According to calculations, grooves deeper

5   than 0.3λ may also achieve a high reflection but are more difficult to manufacture from the point of view of mastering and injection ~~moulding~~molding. The explanation for the reduced reflection above 0.15λ may be that grooves covered with metal act as a waveguide for the radiation beam, thereby lowering the effective reflectivity due

10 to optical effects. At depths $> 0.3\lambda$, these effects may again lead to an increase of the reflection. Since the L_0 stack is recorded on land, i.e., in between the L_0 guide groove generally formed as a spiral, it is required that the thickness d_{L0L} is at least substantially equal to the thickness d_{L1G}. This is because

15 applicants have had the insight that a minimum amount of dye thickness is required in order to have marks recorded which have sufficient modulation. Modulation is defined as the difference of the values of reflection of unrecorded and recorded marks divided by the value of maximum reflection. During recording, the optical

20 properties of the recording layer, e.g., a dye material, are changed due to an increase in temperature. Sufficient modulation can only be obtained if the change in refractive index of the dye (Δn_{dye}) times the thickness of the dye, i.e., $\Delta n_{dye} \times d_{L0L}$, is sufficiently large. If d_{L1G} is chosen such that a modulation of at

25 least 60%, as required by the DVD-ROM specification, is obtained in

recording layer L_1, experiments have indicated that a modulation of at least 60% in recording layer L_0 can only be reached if d_{L0L} is at least equal to or larger than d_{L1G}. Usually the recording layer, e.g., a dye, is deposited using spin coating technique, and therefore, when d_{L0G} is made substantially equal to d_{L1G}, d_{L0L} will be smaller than d_{L1G} because the lands of L_0 will have a shallower recording layer than the adjacent grooves of L_0. When d_{L0L} is substantially equal to or larger than d_{L1G}, this effect is compensated for and a sufficient modulation level of the marks in the L_0 recording layer is achieved combined with a high maximum reflection level. The wavelength λ of the radiation beam is substantially 655 nm (DVD) or smaller for future formats.

[0010]   In an embodiment, d_{L0G} is substantially equal to or larger than $2d_{L1L}$. When using an L_0 guide groove depth of about 1/5 of the L_1 guide groove depth, a relatively high reflection value of the L_0 stack is achieved. The L_0 stack is recorded on-land (as opposed to in-groove) in order to obtain the proper sign of the modulation (high-to-low recording). This has as an additional advantage that the push-pull guide groove tracking signal has the proper sign ("on-land"). The parameter L is defined as: $L = (d_G - d_L)/G$, in which ~~formula~~ d_G is the recording layer thickness in the groove, d_L is the recording layer thickness on land and G is the groove depth. This parameter is a measure for the leveling out of the recording layer after depositing on the groove structure. Normally, when having relatively deep guide grooves of 100 nm or

more and the recording layer is deposited by spin_coating, typically the leveling is between about 0.2 and 0.5. L = 0 means that $d_G = d_L$ and L= 1 means that the top surface of the dye is completely flat after depositing on the guide groove structure. But when using a relatively shallow L_0 guide groove, a leveling factor of L= 1 or close hereto may be assumed. In this case, when d_{L0G} is substantially equal to or larger than $2d_{L1L}$, relatively good recording results are achieved.

[0011]   In another embodiment, the recordable type L_0 and L_1 recording layers comprise an organic dye. In a preferred embodiment, d_{L1G} is larger than d_{L1L}. When using spin coating for depositing the dye of the L_1 recording layer, the grooves will have a thicker recording layer than the adjacent lands. This is advantageous for the recording behavior of the L_1 recording layer because in organic dye based recording, the recording process is optimal when the dye volume, in which the data, i.e., marks, are recorded, is confined within the guide grooves present on the surface of the substrate.

[0012]   In an embodiment, a dielectric layer may be present at a side of the L_0 recording layer opposite from the side where the first reflective layer is present. This has the advantage of even a better modulation. The dielectric layer preferably has a thickness in the range of 5 nm - 120 nm.

[0013]   In yet another embodiment, a second reflective layer comprising a metal is present at a side of the L_0 recording layer

opposite from the side where the first reflective layer is present. Preferably, the second reflective layer has a thickness in the range of 5 nm -15 nm. The second reflective layer preferably mainly comprises a metal selected from the group of Ag, Au and Cu. The

5 second reflective layer has the advantage of an even higher reflection of the L_0 stack. Small variations in stack design may be required to reach a good recording performance.

[0014]   An additional advantage of the use of shallow grooves in an inverted L_0 stack is that a wobble of the guide groove is less

10 visible in the reflection of the radiation beam. A wobble is used to modulate additional information in the guide groove, e.g., an address or time signal. When, e.g., using a guide groove with a depth G_{L0} of 160 nm, a variation of 15% is visible in the signal with the same periodicity as the wobble. At a groove depth G_{L0} of

15 35 nm this variation is substantially absent.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015]   The invention will be elucidated in greater detail with reference to the accompanying drawings, in which:

20 [0016]   Figure 1 shows the reflectivity on a blank area (mirror) and grooved area for an inverted L_0 DVD+R stack. T, in which the groove depth is 126 nm The, and the reflectivity on the grooved area is only about 15% of the reflectivity on the blank area;

[0017]   Figure 2 shows the reflectivity on a blank area (mirror)

25 and grooved area for an inverted L_0 DVD+R stack. The, in which

groove depth is 35 nm. ~~The~~, and the reflectivity on the grooved area is approximately 85% of the reflectivity on the blank area~~.~~;

[0018]   Figure 3 schematically shows a cross-section of an embodiment according to the invention with an inverted L_0 stack~~.~~;

[0019]   Figures 4a and 4b show the calculated result of a modeling study of a stack design according to the invention~~.~~;

[0020]   Figures 5a and 5b show the calculated result of a modeling study of another stack design according to the invention~~.~~; and

[0021]   Figure 6 ~~Reflection~~ show the reflection and modulation calculated for a reference disk~~:~~, i.e., single-layer DVD+R.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0022]   In Fig.1, the results of experiments on inverted L_0 DVD+R stacks are presented when a substrate with a groove depth GL0 of 126 nm, not according to the invention, was used. The reflectivity on the grooved area is approximately 15% of the reflectivity on the blank area (mirror). This value is not acceptable.

[0023]   In Fig.2, the results of experiments on inverted L_0 DVD+R stacks are shown. A DVD+RW substrates with a groove depth of about 35 nm, according to the invention, was used. The reflectivity on the grooved area is approximately 85% of the reflectivity on the blank area, which is significantly higher than for deeper grooves. The disks still shows sufficient push-pull signal, so tracking is possible. Also the experiments show that it is possible to write

data, although the modulation appears to be relatively low (10%, 11T carrier to noise ratio CNR ~ 30 dB) but with the stack design of ~~Fig. 5~~Figs. 5a and 5b, and Fig. 6, a high modulation is possible.

5 The L_0 substrate 31a had 35 nm deep grooves with a FWHM width WL0 of 300 nm, a reflective layer 39 of 100 nm Ag, and 80 nm azo dye recording layer 35, and a protective layer. Typical dyes that can be used are (phthalo)cyanine-type, azo-type, squarylium-type, pyrromethene-type or other organic dye material having the desired

10 properties.

[0024] In Fig. 3, a multi-stack optical data storage medium 30 for recording is shown. A focused radiation beam, i.e., a 655 nm laser-light beam 40, enters through an entrance face 41 of the medium 30 during recording. The medium comprises a first substrate

15 31a ~~with present~~having, on a side thereof, a first recording stack 33 ~~named~~, L_0, comprising a recordable type L_0 recording layer 35, i.e., an azo dye. The L_0 recording layer is formed in a first L_0 guide groove 38 present in the first substrate 31a, and a first reflective layer 39 is present between the L_0 recording layer 35

20 and the first substrate 31a. A second substrate 31b is present ~~with~~ having, on a side thereof, a second recording stack 32, ~~named~~ L_1, comprising a recordable azo dye type L_1 recording layer 34. The second L_1 recording stack 32 is present at a position closer to the entrance face than the L_0 recording stack 33 and formed in a second

25 L_1 guide groove 37. A transparent spacer layer 36 is sandwiched

between the recording stacks 32, 33 and has a thickness of approximately 40 μm. The first L_0 guide groove 38 has a depth of 35 nm. The first substrate 31a with L_0 is attached to the substrate with L_1 with the transparent spacer layer 36 in between which may

5   act as bonding layer. A semi-transparent reflective layer 42, comprising, e.g., Cu or Ag, is present adjacent the L_1 recording layer 34. Specific suitable L_0 stack designs named stack 1 and stack 2 are discussed elsewhere in this document with the description of Figs. 5a and 5b, and Fig.6. The preferred spacer-

10 layer thickness for both disk types is 40 μm to 70 μm. One specific embodiment would be:

L_1: d_{L1G} = 80 nm, d_{L1L} = 30 nm dye/ 12 nm Ag/ UV curable resin (protective layer),

————————L_1 guide groove depth 160 nm;

15 L_0: 100 nm $(ZnS)_{80}(SiO2)_{20}$ / d_{L0L} = 120 nm, d_{L0G} = 150 nm dye/ 100 nm Ag,

————————L_0 guide groove depth 30 nm;

and a spacer thickness of 50 μm. The effective reflection from L_1 is about 19%, effective reflection (measured through L_1) from L_0 is

20 about 19%.

The upper L_1 stack of a recordable dual-stack DVD disk should have high transparency in order to be able to address the lower lying L_0 stack. At the same time, L_1 preferably should have a reflectivity of at least 18% in order to meet the dual layer DVD-ROM

25 specification. The stacks proposed here are not restricted to use

in DVD+R-DL and can be applied in any (multi-stack) organic-dye based optical recording medium.

[0025]   In Figs.4a and 4b, modeling results are presented of a stack with the following design:

5 Stack 1:

-        30 to 40 nm deep guide grooves in substrate 31a,

-        an optically closed Ag first reflective layer 39 of 100 nm. Other metals, e.g., Au, Cu or Al, may be used as well,

-        an azo dye layer, with thickness of 130 nm on land, the

10 refractive index of the dye at a radiation beam wavelength of 655 nm is 2.24 - 0.02i which corresponds to a typical DVD-R dye,

-        80 to 120 nm $(ZnS)_{80}(SiO2)_{20}$, other dielectrics with n ~ 2.1 give identical results.

[0026]   This design combines a high reflectivity and a high

15 modulation of the inverted L_0 recording stack for the case of shallow grooves. The stacks should be recorded on-land (as opposed to in-groove) in order to obtain the proper sign of the modulation (high-to-low recording). This has as an additional advantage that the push-pull signal has the proper sign ("on-land"). The

20 definition of parameter L is described earlier.

[0027]   In Fig 4a, the calculated results of the on-land reflection as a function of the on-on-land dye thickness d_L are shown.

[0028]   In Fig. 4b, the calculated results of on-on-land

25 modulation as a function of the on-on-land dye thickness d_L are

shown. The horizontal dotted line indicates a minimum desired level. It can be noted that the desired level is reached at a dye thickness range of about 100-130 nm.

[0029] Experimental results obtained with this stack 1 are: A high modulation of 75% and a high reflection level of 61%. Modulation is generally defined as $(R_{mark}-R_{no-mark})/ R_{max}$ in which formula R_{mark} and $R_{no-mark}$ are the reflection levels from the read out laser beam when, respectively, a written mark and no mark is present and R_{max} is the maximum reflection. The laser beam power required to write in the L_0 layer is only 7 mW, which is favorable in view of the presence of the L_1 stack because a relatively large portion of the power will be absorbed in the L_1 stack.

[0030] In Figs.5a and 5b, modeling results are presented of a stack with the following design:

Stack 2:

- 30 to 40 nm deep guide grooves in substrate 31a,

- an optically closed Ag reflective layer 39 of 100nm, other metals, e.g., Au, Cu or Al, may be used as well,

- an azo dye layer, thickness 100 to 130 nm on land, the refractive index of the dye at a radiation beam wavelength of 655 nm is $2.24 - 0.02i$ which corresponds to a typical DVD-R dye,

- a 5 to 15 nm second reflective layer of Ag, other metals, e.g., Au or Cu, may be used as well.

[0031] Experimental results obtained with this stack 2 are: A high modulation of 75% and a high reflection level of 64%. The

laser beam power required to write in the L_0 layer is only 7 mW, which is favorable in view of the presence of the L_1 stack because a relatively large portion of the power will be absorbed in the L_1 stack.

[0032]   A third stack design is possible which is not shown in a ~~drawing~~ drawings but is described here:

Stack 3:

-         30 to 40 nm deep guide grooves in substrate 1a,

-         an optically closed Ag reflective layer 39 of 100nm, other metals, e.g., Au, Cu or Al, may be used as well,

-         an azo dye layer 35, thickness 90 nm to 160 nm on land, the refractive index of the dye at a radiation beam wavelength of 655 nm is 2.24 - 0.02i which corresponds to a typical DVD-R dye,

-         a 5 to 50 nm layer of SiO2, other dielectrics may be used as well.

[0033]   The advantage of this third stack design is that it is more easy to manufacture compared to the second stack design.

[0034]   In Fig.6, as an example, the result for a conventional single stack DVD+R disk is shown. The refractive index of the dye is taken as 2.24 - 0.02i (this corresponds to a typical dye). According to the calculations, around a thickness of 80 to 90 nm of dye, both the on-groove reflection curve 72 and the on-groove modulation curve 71 are at optimum values. The calculated reflectivity and modulation agree well with experimentally obtained values. To achieve good signal quality from the L_0 layer, it was

attempted to obtain stack designs that combine high reflectivity with a high modulation (both > 60 %). It turns out that for a straightforward three-layer stack-design, in-groove recorded signals have the wrong polarity (low-to-high recording, not shown) in most cases. Thus for the case of shallow grooves, on-land recording may be considered, or more complicated stack designs.

[0035]   Both stack designs of Figs. 4a/4b and Figs. 5a/5b according to the invention have a recorded mark modulation value and an effective L_0 stack reflection value that is relatively high, i.e., meeting the dual-layer DVD specification. Note that the stacks proposed here are optimized for relatively shallow grooves, i.e. approximately 35 nm but that other groove depths are possible, e.g., < 80 nm. The optimal groove depths scales with the radiation beam wavelength λ.

[0036]   It should be noted that the above-mentioned embodiment illustrates rather than limits the invention, and that those skilled in the art will be able to design many alternative embodiments without departing from the scope of the appended claims. In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. The word "comprising" does not exclude the presence of elements or steps other than those listed in a claim. The word "a" or "an" preceding an element does not exclude the presence of a plurality of such elements. The mere fact that certain measures are recited in

mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

[0037]   According to the invention a multi-stack optical data storage medium for recording using a focused radiation beam having a wavelength λ and entering through an entrance face of the medium is described. It has a first substrate ~~with present~~having, on a side thereof, a first L_0 guide groove formed therein, and a first recording stack ~~named~~ L_0, comprising a recordable type L_0 recording layer~~, and formed in a first L_0 guide groove~~. The L_0 recording layer has a thickness d_{L0G} in the groove and a thickness d_{L0L} adjacent the groove, and a first reflective layer present between the L_0 recording layer and the first substrate. A second substrate has~~,~~ ~~present~~ on a side thereof, a second L_1 guide groove formed therein, and a second recording stack ~~named~~ L_1 comprising a recordable type L_1 recording layer. The L_1 recording layer has a thickness d_{L1G} in the groove and a thickness d_{L1L} adjacent the groove. The second recording stack is present at a position closer to the entrance face than the L_0 recording stack ~~and is formed in a second L_1 guide groove~~. The depth of the first L_0 guide groove is smaller than 0.15λ and d_{L0L} is substantially equal to or larger than d_{L1G}, by which it is achieved that the L_0 stack has a reflection level and a modulation level of recorded marks compatible with the dual layer DVD-ROM specification.

ABSTRACT~~,~~ OF THE DISCLOSURE

A multi-stack optical data storage medium ~~(30)~~, for recording using a focused radiation beam ~~(40)~~ having a wavelength λ and entering through an entrance face ~~(41)~~ of the medium ~~(30) is described. It~~, has a first substrate ~~(31a) with present~~ having ~~on a side thereof~~ a first guide groove formed therein, and a first recording stack ~~(33) named L_0,~~ ~~comprising~~ including a recordable type ~~L_0~~ recording layer ~~(35), and formed in a first L_0 guide groove (38). The L_0 recording layer (35) has~~ having a thickness d_{L0G} in the groove ~~(38)~~ and a thickness d_{L0L} adjacent the groove ~~(38)~~. A second substrate ~~(31b)~~ has ~~present on a side thereof~~ a second guide groove formed therein, and a second recording stack ~~(32) named L_1~~ ~~comprising~~ including a recordable type ~~L_1~~ recording layer ~~(34). The L_1 recording layer has~~ having a thickness d_{L1G} in the groove and a thickness d_{L1L} adjacent the groove. The second recording stack ~~(32)~~ is ~~present~~ at a position closer to the entrance face ~~(41)~~ than the ~~L_0~~ first recording stack ~~(33) and is formed in a second L_1 guide groove (37)~~. The depth of the first ~~L_0~~ guide groove ~~(38)~~ is smaller than 0.15λ and d_{L0L} is substantially equal to or larger than d_{L1G} ~~by which it is achieved that the L_0 stack (33) has a reflection level and a modulation level of recorded marks compatible with the dual layer DVD ROM specification~~.